CONCEPTUAL DESIGN OF THE ESS DTL FARADAY CUP

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Abstract

The DTL section of the ESS linac will accelerate the beam form 3.6 MeV to 90 MeV at a peak current of 62.5 mA. It is foreseen to install after each DTL tank a Faraday cup for beam current and the beam transmission measurements during retuning phase. An energy degrader will be positioned in front of the in order to perform a low resolution phase scan of the DTL tank before injecting the beam in the downstream structure. This paper describes the preliminary studies of the Faraday cup, mainly focus on the energy degrader.

INTRODUCTION

The European Spallation Source (ESS) is a neutron source based on a 5 MW proton linac, build in Lund, Sweden. The normal conducting front end will accelerate the beam coming for the ion source up to 90 MeV, it consists in an ECR ion source, a Low Energy Beam Transport line (LEBT), a radio frequency quadrupole (RFQ), a Medium Energy Beam Transport line (MEBT) and a drift tube linac (DTL) [1].

The DTL employs a permanent magnet FODO lattice leaving empty drift tubes for diagnostics like BPMs and Beam current Transformer. The inter-tank regions will each house a wire scanner and a Faraday Cup (FC), a preliminary layout of the beam diagnostic is shown in Fig. 2.

In total 5 FC will be installed in the DTL section, they consist in a charge collector positioned downstream an energy degrader, in order to study the transmission of the beam in function of the RF phase and amplitude in the DTL cavity (see Fig. 1).

The degrader thickness is chosen to stop incoming beam with energy slightly below the cavity design output.

The cavity phase and amplitude are scanned, for each point the signal on the FC is measured and at the end of the process an acceptance can be determined by looking at he width of the signal

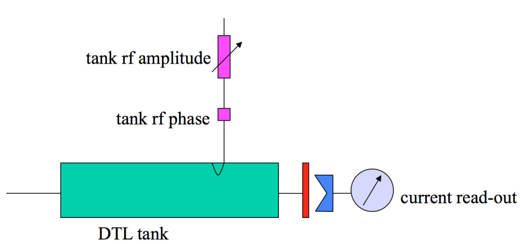

Figure 1: Schematic of the energy degrader method from phase scan measurement in the DTL, the energy degrader is represented in red and the charge collector in blue.

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FARADAY CUP DESIGN

As all the other interceptive devices installed in the ESS linac, the FCs will not be able to withstand the full beam power. They will be used only during commissioning and dedicated study periods with reduced beam power, the different machine modes are shown in Tab. 1.

Table 1: ESS beam parameters during operation (left) and during retuning and commissioning phases.

	Operation	Fast mode	Slow mode
I $[mA]$	6 to 62.5	6 to 62.5	6 to 62.5
Pulse length $[\mu s]$	2860	10	100
Rep. Rate [Hz]	14	14	1

All the simulations presented in this paper have been done with the maximum beam intensity.

Beam parameters

The nominal beam parameter at the FCs location are summarized in Tab. 2.

Table 2: Beam parameters at the DTL FC location, FC are named according to their position in Fig. 2.

Position	σ_x [mm]	σ_y [mm]	Energy [MeV]
FC1	1.7	1.2	21.29
FC2	1.3	2	39.11
FC3	1.8	1.6	56.81
FC4	1.6	1.9	73.83
FC5	2.6	1.8	89.91

The beam sizes will slightly change during the RF scan of the DTL cavity, for the studies presented in this paper, average beam sizes of σ_x= 1 mm σ_y = 2 mm have been assumed for all inter tank area and for all beam energies, and also for FC5 in the case of this FC will be installed at the exit of the last tank.

Energy degrader parameters

The energy deposition on a single energy degrader is too high for the ESS beam parameters. In order to cop with the higher beam power, the energy degrader consists in two foils separated by 30 mm, an example of the geometry used in the simulation is show in Fig. 3.

For a given FC, the thickness of the first is chosen in order to let the beam goes thought if the upstream cavity is not powered. The Multiple scattering in the foil increase the beam divergence and thus reduced the beam density on the second foil. The thickness of the second foil is chosen in function of the threshold energy required for the FC.

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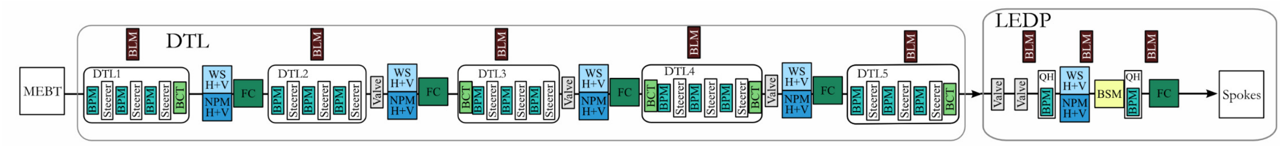

Figure 2: Beam instrumentation layout in the ESS DTL.

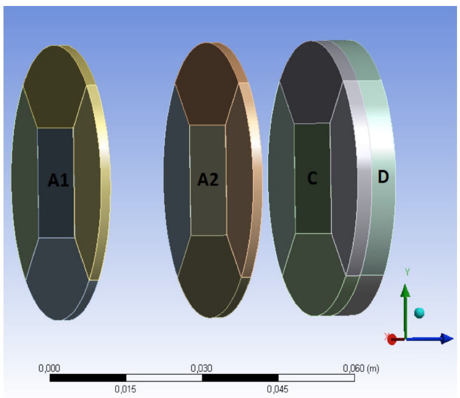

Figure 3: Example of FC geometry in FE code, A1 is the first foil, A2 the second and C the collector.

The main drawback of this design is the length increase of the FC, and it will be used only if the space allocation between DTL tanks allows the insertion of a 70 mm long device. After tank 1 and tank 2, a single energy degrader has to be used. The material and the thickness of the energy degrader are summarized in Table 3.

Table 3: Material and thickness of the energy degrader of the different FC installed in the DTL.

	Material	Foil 1 thickness [mm]	Foil 2 thickness [mm]
FC2	carbon	7.5	–
FC3	TZM	2	2
FC4	TZM	4	3
FC5	TZM	5	5

For the first faraday cup, the beam power density will be too high at 3.6 MeV to have a safe use of the FC with all modes considered. The transmission in the first DTL tank of a low energy beam will not be efficient, beam dynamic simulations will give more precise value of the minimum energy at the exit of the tank as well as more accurate beam sizes. A new design for this FC will be studied in the next months.

Collector

The collector is positioned 2 cm downstream the second foil (for FC3, FC4 and FC5) and up to 3 cm from the foil in FC2 case. It consists of thick TZM foil (3 mm) electrically isolated from the other part of the FC, the charge deposited in the collector will be readout by a dedicated electronic.

A bias ring is positioned upstream the collector to suppress secondary electrons from the foil and the collector. The mechanical assembly of this bias ring is still under discussion.

Beam transmission

The Monte Carlo code FLUKA [2] has been used to estimate the threshold energy and the current transmission of the FCs. The input energy of the simulation has been varied by step of 0.5 MeV, the results for the fourth last FC are shown in Fig. 4.

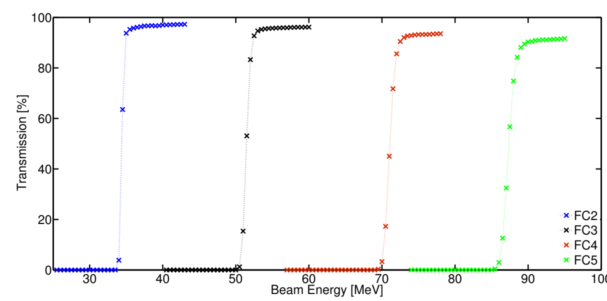

Figure 4: Transmission in the FC as function of the beam energy for the last four FC.

For all the FCs considered, the transmission never reaches 100 %. In the worst case the transmission is about 90 %. Due the finite diameter of the collector, a part of the protons scattered at large angle are not collected and reduces the transmission. At high energy and for heavy material, the number of nuclear interaction can not be neglected and reduced the transmission as well.

The DTL FCs will be not be able to measure precisely the beam current, nevertheless for RF scan of the DTL cavities, a precise value of the beam current is not mandatory.

FINITE ELEMENT ANALYSIS

With the same Monte Carlo code, energy deposition maps have been estimated for the last three FCs. The beam energy chosen for these estimations are:

- Beam energy at the tank exit without RF power
- Beam energy before the threshold, defined with the previous simulations
- Nominal output energy of the tank

The results have been used in the simulation software ANSYS® in order to estimate the temperature and mechanical

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stresses induced by the beam on the FCs. The same boundary conditions have bee used for all cases, the energy degraders are thermally isolated from the rest of the FC, and the lateral surfaces have a constant temperature of 25 $°C$. The surface in the backside of the FC has also a constant temperature of 25 $°C$. All stress in this analysis is the equivalent von Mises stress.

A first set of simulations have been performed to estimate the temperature in the 2 energy degraders for a single pulse. The results for a 10 μs pulse are shown in Tab. 4.

Table 4: Maximum temperatures in the energy degraders after one 10 μs pulse.

FC	Beam Energy [MeV]	T_{max} foil 1 [$°C$]	T_{max} foil 2 [$°C$]
FC3	40	316	129
	50	210	184
	57	180	98
FC4	57	273	95
	69.5	176	128
	74	162	85
FC5	74	177	108
	85.5	145	120
	90	137	85

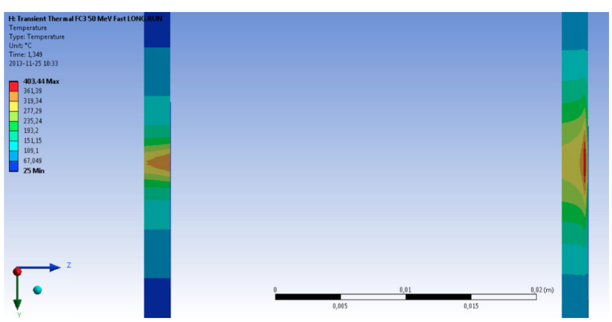

Figure 5: Temperature distribution after 20 pulses in the two energy degraders of FC3 at 50 MeV (fast mode).

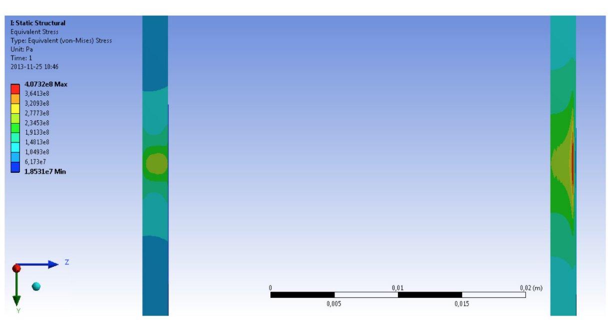

Figure 6: Stress distribution after 20 pulses in the two energy degraders of FC3 at 50 MeV (fast mode).

Same simulations have been done with a 100 μs pulses, results show that the temperature is almost multiple by a factor 10, which leads to damage on the FCs, in consequence the FCs can be used with longer pulses only if the beam current is reduced, more FE analysis have to be performed to find the limits in beam current.

In a second step, transient thermal analysis with 20 consecutive 10 μs pulses have been performed for the 3 FCs considered and all energies presented in Tab. 4.

The maximum stress appears in the second foil of FC3 for a beam energy of 50 MeV, in this case the peak temperature is close to the surface leading to high temperature gradient and high stresses in the material. The temperature distribution and the stress in the two energy degraders at this energy are presented in Fig. 5 and Fig. 6.

The temperature reaches a maximum of 674 K in the second foil and a maximum stress of $\approx$ 410 MPa, below the limits of the material considered.

Similar results can be observed for FC4 and FC5, the maximum stress is observed when the beam energy is closed to the energy threshold. The same calculations have been performed for the collector, in all case considered, the temperature and the mechanical stresses are far below the mechanical limits of TZM and are not presented in this paper.

From these studies, it can be concluded that the FCs considered can be used safely during the fast tuning mode.

CONCLUSION AND OUTLOOK

The design of the two first FCs might be more complicated than the last ones, space limitation and lower beam energies imply the use of a single energy degrader. The mechanical stresses might be too high even with the shortest pulse, material and foil thickness as well as the shape and material of the collector have to be chosen to at least withstand this mode.

In parallel, a new set of simulation will be done for the last FC with realistic beam sizes (shown in Tab. 2). This FC might be used as a beam stopper and are less constraint by the space available if it is positioned in the LEDP (not decided at the time the paper is written). In this case the FC has to absorb the beam of all the beam mode during commissioning and retuning of the warm linac in order to avoid losses in the superconducting linac.

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